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Influence of various parameters of cryogenic treatment on performance of tungsten carbide tool - A review

Mansi Lakhani[1]
[1]*(Department of Mechanical Engineering, VIVA Institute of Technology, India)*

Abstract : *Cryogenic treatment is supplementary thermal treatment done after conventional hardening process, wherein hardened material is further cooled till cryogenic temperatures which may range from -80°C to -196°C. In the case of various grades of steel, the cryogenic treatment process has proved to have improved mechanical properties significantly through conversion of retained austenite to martensite and refinement of grain structure of steel. However, the effect of cryogenic treatment on high hardness material like tungsten carbide is still in research and results are uncertain. Ongoing research have suggested that cryogenic treatment may result into improvement of hardness and wear resistance of tungsten carbide tools which in turn may improve tool life and efficiency of the cutting operation. But, the amount of improvement in properties majorly depends of various parameters of cryogenic treatments. This paper deals with reviewing various parameters of cryogenic treatment like cooling cooling rate, soaking temperature, soaking time, tempering temperature, tempering time and its effect on performance of tungsten carbide tool.*

Keywords - *cryogenic treatment, tungsten carbide, performance evaluation, tool life, mechanical properties, soaking time, soaking temperature, cooling rate*

I. INTRODUCTION

In current metal cutting industry, tungsten carbide (WC) has almost entirely replaced carbon steel in the manufacturing of metal cutting tools owing to its exceptional hot hardness properties. In the manufacturing of tungsten carbide tools, the fine and hard carbide particles are cemented to the soft cobalt binder, making it a metal matrix composite and usually referred as WC-Co hard metal.

Application of high-speed machining to achieve a high material removal rate resulted in alloying the tungsten carbide material with carbides of transition group metals like niobium, chromium, zirconium, titanium, and vanadium to improve the core properties of base metal. Nevertheless, due to the invention of newer work materials, the demand to further increase the wear resistance of cutting tools resulted in the invention of harder coatings.[1] Though the advanced techniques like "alloying" and "coating" have improved the life of tungsten carbide-based tools significantly,[1] the processes are relatively complex and expensive.

Cryogenic treatment of steel and steel alloys is been widely accepted as a supplement process to conventional heat treatment that can aid in almost complete transformation of austenite to martensite with some other microstructural changes that enhances properties of steel. In case of steel, cryogenic treatment post conventional heat treatment results in improvement in mechanical properties like tensile strength, hardness, wear resistance, impact strength. The commercial success of cryogenic treatment on ferrous materials and its alloys, allowed the researchers to focus on studying and establishing an appropriate process parameter to super hard tool materials like tungsten carbide.

This paper aims to review and summarize the key research findings about the various parameters related to cryogenic treatment of tungsten carbide material, and how each parameter may affect the performance and properties of cutting tools made up of tungsten carbide.

II. CRYOGENIC PROCESSING

Cryogenic treatment is a supplementary process to conventional heat treatment, and is done after hardening and before tempering of steel [2] [3]. It involves deep freezing of materials at cryogenic temperatures.

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The process of cryogenic treatment involves cooling the material uptil cryogenic temperatures at a constant cooling rate (known as ramp down rate), holding the material at that temperature for specific time (known as soaking period), then bringing the material back to the room temperature at constant heating rate (known as ramp up rate). Soaking temperature, soaking period, ramp down rate and ramp up rate are parameters of the cryogenic treatment that affects the output of the treatment [4]. Fig. 1 shows typical cycle of cryogenic treatment.

Cryogenic treatment can be broadly classified as Shallow cryogenic treatment and deep cryogenic treatment. In case of shallow cryogenic treatment the optimal treating temperature is around 80°C, holding time varies between 5 hours to 8 hours. Also, there is not any specified ramp up and ramp down rate in shallow cryogenic treatment. Deep cryogenic treatment consists of treating temperature around -196°C with the holding time between 16 hours to 48 hours. Also, in case of DCT uniform ramp up and ramp down rate is maintained [5]. Most of the cryogenic treatment cycles have been developed empirically and the treatment shows different results for different materials. The result also varies with variation in parameters off cryogenic treatment.[5]

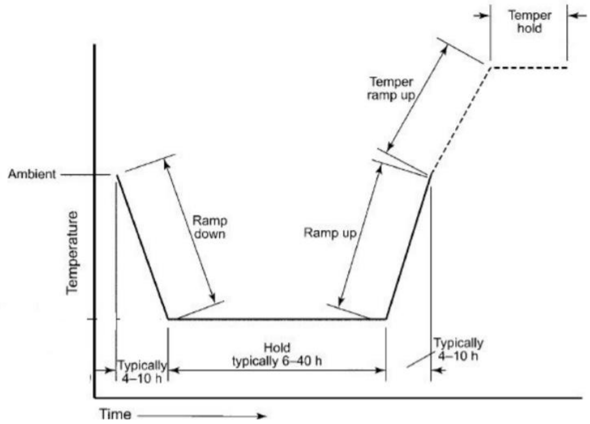

Fig. 1 – Time Temperature Plot for Cryogenic Processing

Various parameters that can affect the performance of cryogenically treated material are soaking temperature, ramp up rate, ramp down rate, holding period, tempering period, tempering temperature.

III. EFFECT OF SOAKING TEMPERATURE

Soaking temperature is the temperature at which the materials are treated. Usually, the temperature depends on the type of cryogen used for the study [6] and this single factor contributes around 72% for performance improvement.[7,8] Researchers have varied the soaking temperature between −30°C to −196°C and studied the behavior of treated tools. Coated turning inserts were cryogenically treated at two different soaking temperatures of −110°C and −196°C and the wear behavior was compared by Gill et al.[9] They have reported that tools treated at lower temperature enhanced the life by around 25%, whereas the tools treated at −196°C degraded the performance by weakening the bond between the coating and tungsten carbide substrate.

Other studies where −196°C is used as soaking temperature have reported a good performance improvement. It also shows that around −196°C (the boiling point of LN2) is the frequently used and the lowest temperature at which the materials were soaked. As liquid nitrogen is the most frequently used industrial cryogenic fluid and is non-hazardous, the majority of the studies have used it as the cryogen.[10]. Hence, a constant temperature of −196°C or lesser and a variable soaking period would be the preferred combination for future investigations.

IV. EFFECT OF SOAKING TEMPERATURE

The duration for which the materials are treated is the soaking period and it is the second significant factor with around 16 to 30% contribution to the performance improvement.[11].

In an experiments with turning uncoated tungsten carbide insert soaked for 18, 24, and 32 hours, it was observed that 24 hours is the optimum soaking period to achieve higher machinability[12]. Another study [13] shows that cryogenic treatment increases the micro-hardness and compressive strength without affecting the bending strength and toughness. But it has also noted that an increase in soaking time did not increase the mechanical properties of tungsten carbide.

From the review, it is suggested that additional optimization studies must be performed to evaluate the ideal soaking period for the material-specific requirements.

V. EFFECT OF RAMP DOWN & RAMP UP RATE

The pace at which the material is cooled down to cryogenic temperature is the ramp down rate, whereas the pace at which the samples are brought back to ambient temperature is the ramp up rate. It is the third most influential variable in the cryo-treatment technique with a significance of around 10%, next to soaking temperature and soaking period [11].

A study [14] have determined that the cooling rate must be in the range of 20–30°C/h to avoid cooling stress which could rupture the material. Whereas another study [15] probed the consequence of varying cooling rates on the behavior of WC-Co turning tools. Their report shows that tools treated at 0.5°C/min precipitated fine eta-carbides which increased the hardness and toughness, whereas the tools treated at 1°C/min showed lesser carbide precipitation; higher wear rate, and lower surface quality.

Other studies conducted at both low[16,17] and high[18,19] cooling rates have given a significant performance improvement in tungsten carbide material. However, slow cooling and warming rate increases the overall process time which in turn increases the cost. So, to avoid thermal shocks and get the maximum benefit out of the treatment, it is suggested to maintain a minimal rate of cooling and warming.

VI. EFFECT OF TEMPERING PROCESS

Darwin et al.[11] have proven that tempering has a negligible effect on performance improvement with a significance of less than 2%. In line with their findings, many researchers have either performed one tempering or no tempering at all and have considered tempering as the least preferred step in the cryo-treatment process. However, Kalsi et al.[20] have observed that tempering stabilizes the tungsten carbide material by releasing the internal stress that was formed during cryogenic treatment.

The compressive and tensile stresses from the carbide and cobalt phases that are formed because of the large variance in the thermal expansion coefficient of the two materials were reduced by exposing the samples to repeated tempering cycles. By studying the metallurgical and mechanical properties, they have concluded that increasing the number of tempering cycles decreases the micro hardness, whereas the highest wear resistance was achieved for the inserts treated with double and triple tempering.

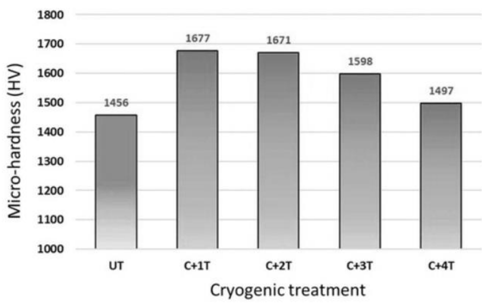

Fig 02 - Micro-hardness of tungsten carbide samples with different tempering cycles.[20]

A study[21] has reported that precipitation of fine, homogeneously distributed carbide particles occurs only when tempering is performed after cryogenic treatment. Whereas, another study [22] have reported no change in the metallurgical properties in the samples that have undergone an additional tempering cycle. The literature study shows that tempering is one of the key stages that was given the least importance in most studies and hence must be adequately clarified and optimized to get the maximum benefit out of cryogenic treatment.

VII. CONCLUSION

Cryogenic treatment is one of the successful post-processing treatments which has shown a significant improvement in the performance of carbon steel and other ferrous based cutting tool materials. Nevertheless, it was believed during earlier days that cryogenic treatment would not have any effect on hard metal like tungsten carbide, as the material is stable to such thermal treatments. But many researchers have taken the challenge and provided their valuable contributions to understand the possible mechanism involved in the tungsten carbide tool material.

Soaking temperature, duration of soaking and ramp up and ramp down rates are the critical cryogenic process parameters that were given importance by most of the researchers. However, some studies show that an appropriate tempering process also plays a significant role in performance improvement which needs further clarification. Soaking temperatures of around −196 C, soaking duration of 24 hours, and tempering temperature of around 200 C are the commonly used cryogenic process parameters. Most of the researchers have agreed that the slowest possible cooling and warming rate is preferred; however, there are no suggestions on the ideal rate.

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